VIBRATION ELEMENT AND VIBRATION WAVE DRIVING APPARATUS

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to a vibration wave driving apparatus, and more particularly, to a configuration of a vibration element used in a bar-shaped vibration wave driving apparatus.

Related Background Art

A bar-shaped vibration wave driving apparatus includes, as a basic structure, a vibration element composed of elastic members made of metal or the like and a piezoelectric element as an electro-mechanical energy conversion element. The bar-shaped vibration wave driving apparatus generates a driving vibration such as a travelling wave or the like through application of an alternating voltage as an alternating signal with different phases to the piezoelectric element.

A contact member is brought into pressure contact with a frictional surface of the elastic member through a pressurizing means and the contact member is frictionally driven by the driving vibration generated in the frictional surface of the elastic member to allow the vibration element and the contact member to be moved relative to each other.

There is a vibration wave motor as an example of

such a vibration wave driving apparatus in which a vibration element is used as a stator and a contact member as a rotor.

Examples of the vibration element of the vibration wave motor include those with a configuration in which a ring-shaped piezoelectric element plate is attached to one surface of a ring- or disc-shaped elastic member and those of a type in which the rotation of the rotor is taken out through an output shaft or of a type in which the rotation of the rotor is taken out directly.

Such a vibration wave motor has been applied to products to be used for driving a camera lens and the like. There are annular type and bar-shaped type vibration wave motors.

FIG. 10A is a structural view of a vibration element of a bar-shaped vibration wave motor used for driving a camera lens. FIG. 10B shows a vibration mode (with the z-axis assigned to the axial direction and the r-axis assigned to the radial direction) in an axis part of the bar-shaped vibration element.

Reference numeral 101 indicates a first elastic member; 102, a second elastic member; and 103, a piezoelectric element. Reference numeral 106 denotes a shaft member passing through the first elastic member 101, the piezoelectric element 103, and the second elastic member 102. One end of the shaft member 106 located on the side of a rotor 110 is fixed to a

fitting member 109 to be attached to a product and the other end is fixed to a nut 115. A threaded portion is formed in the other end of the shaft member 106. With the nut 115 tightened, the first elastic member 101, the piezoelectric element 103, and the second elastic member 102 disposed between a flange portion provided for the shaft member 106 and the nut 115 are sandwiched and fixed therebetween. Reference numeral 110 indicates the rotor as described above, and Reference numeral 107 denotes a friction member fixed to the first elastic element 101 to be in contact with the rotor.

When a driving signal is applied to the piezoelectric element 103, the bending vibration (in FIG. 10B primary bending vibration) indicated in FIG. 10B is excited in the bar-shaped vibration element, whereby the bar-shaped vibration element makes a swing movement substantially about the z-axis. Accordingly, the friction member 107 makes a circular motion around the z-axis.

It seems that the vibration element of such a bar-shaped vibration wave driving apparatus has been reduced in size in its radial direction, but there is still room for reduction in size in its thrust direction, i.e. in length of its axis.

However, when the vibration element is simply shortened, there arise problems in that the resonance

frequency increases and the vibration displacement is reduced, which causes the deterioration in efficiency of friction drive, the increase in price of a driving circuit element due to the high frequency, or the increase in loss inside the element. Further, when the vibration element is simply made thinner to lower the resonance frequency, the diameters of a piezoelectric element and a frictional surface are also reduced and thus generating force of the piezoelectric element and the friction torque also decrease. Therefore, it is conceivable that the output of the motor is made small.

As a technique for solving the above problems and shortening the axial length of a bar-shaped vibration wave driving apparatus, there is one disclosed in Japanese Patent Application Laid-open No. 2001-145376, which is shown in FIG. 11.

A vibration apparatus in such document is identical to a conventional product in that a piezoelectric element 203 is sandwiched and fixed between a first elastic member 201 and a second elastic member 202. However, it is different from the conventional product in that the first elastic member 201 with a frictional surface is divided into an inner diameter portion and an outer diameter portion that are connected to each other through a thin connection part 210.

According to this construction, even if the axial

length of the bar-shaped elastic member is shortened, a low resonance frequency can be obtained since the first vibration element has a sufficiently high mass.

According to this technique, however, when the connection part 210 is made thin to allow the resonance frequency to be lowered and its rigidity is deteriorated, the displacement generated in the piezoelectric element is absorbed by a soft spring of the connection part 210. Consequently, it is difficult to transmit the driving force to a rotor efficiently. Thus, it seems that there is still room for further improvement.

SUMMARY OF THE INVENTION

One aspect of this invention is to provide a vibration wave driving apparatus including an electro-mechanical energy conversion element that is sandwiched and fixed between elastic members, wherein a third elastic member is provided between the electro-mechanical energy conversion element and one of the elastic members. The third elastic member has a large diameter than that of the electro-mechanical energy conversion element. When a driving vibration is applied to the electro-mechanical energy conversion element, a vibration element excites a bending vibration and this bending vibration allows an out-of-plane bending vibration to be excited in the third

elastic member. Since a rotor is brought into contact with the third elastic member sandwiched between the elastic member and the electro-mechanical energy conversion element, the size of the vibration wave driving apparatus can be reduced. In addition, since a travelling wave produced by the bending vibrations of the vibration element and a travelling wave produced by the out-of-plane bending vibrations of the third elastic member are generated at the frictional surface of the vibration element, the output of the vibration wave driving apparatus can be improved.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a cross-sectional view of a vibration element showing a first embodiment of the present invention.

FIGS. 2A and 2B each are a vibration mode diagram used for explaining a driving principle of the present invention.

FIGS. 3A and 3B each are a diagram illustrating a vibration mode of a vibration element showing a driving principle of the present invention.

FIGS. 4A and 4B each are a diagram illustrating another vibration mode of a vibration element showing a driving principle of the present invention.

FIG. 5 is a cross-sectional view of a vibration element showing a second embodiment of the present

invention.

FIG. 6 is a cross-sectional view of a vibration element showing a third embodiment of the present invention.

FIGS. 7A and 7B are a perspective view and a cross-sectional view, respectively, of a vibration element showing a fourth embodiment of the present invention.

FIG. 8 is a cross-sectional view of a vibration element showing a fifth embodiment of the present invention.

FIG. 9 is a structural view of a vibration wave driving apparatus showing a sixth embodiment of the present invention.

FIG. 10A is a cross-sectional view of a conventional bar-shaped vibration wave driving apparatus and FIG. 10B is a diagram illustrating a vibration mode of its vibration element.

FIG. 11 is a cross-sectional view of a conventional vibration wave driving apparatus with a shortened axial length.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

First Embodiment

The problem of the invention disclosed in Japanese Patent Application Laid-open No. 2001-145376 is caused because the mass member attached to an end of a soft

spring (connection part 210) serves as a frictional surface. Hence, it is conceivable that this problem can be solved through separation of a functional member for lowering the resonance frequency and a functional member for taking out driving force from each other.

FIGS. 1A, 1B and 1C show a first embodiment of the present invention. Reference numeral 1 denotes a first elastic member formed in a cylindrical shape, which is made of a material whose vibration damping loss is small, such as brass. Reference numeral 5 denotes a flange-shaped (disk-shaped) elastic member, which is made of ceramic, such as alumina.

In FIG. 1, the vicinity of the outer periphery of the surface of the flange-shaped elastic member 5 located on the opposite side to an piezoelectric element 3 is a portion that comes into contact with a rotor and is formed to be slightly thicker like its center portion in which the flange-shaped elastic member 5 is supported and fixed by the first elastic member 1. This is intended to reduce the area to be subjected to lapping process by allowing the region between the center portion and the vicinity of the outer periphery to be recessed, and thereby to reduce processing time. In this case, as is apparent from FIG. 1, the vicinity of the outer periphery of the flange-shaped elastic member 5 extends outward beyond the outer peripheral portions of the first elastic

member 1 and the piezoelectric element 3 that are adjacent to the flange-shaped elastic member 5.

Reference numeral 3 denotes a group of piezoelectric elements. As the group of piezoelectric elements, one of a stacked type is disposed that is formed with a plurality of elements having electrodes on its both upper and lower sides or a plurality of thin-film piezoelectric members having electrodes on its both upper and lower sides stacked and hardened by heating to form one body.

Reference numeral 2 indicates a second elastic member that also is formed of a material with a low vibration damping loss as in the case of the first elastic member 1.

The first elastic member 1, the second elastic member 2, the flange-shaped elastic member 5, and the piezoelectric element 3 are combined to form one body by means of a shaft member 6 as a fastening means. The shaft member 6 with a threaded portion formed on its one end is inserted from the end portion of the first elastic member 1 to be passed through the piezoelectric element 3 and then the threaded portion is screwed together with an internal threaded portion formed in the axis center portion of the second elastic member 2. The flange-shaped elastic member 5 and the piezoelectric element 3 are disposed between the first elastic member 1 and the second elastic member 2 and in

this state, the whole can be sandwiched and fixed by a flange portion provided for the shaft member 6 in its middle portion and the threaded portion provided at an end portion of the shaft member 6. The other end portion of the shaft member 6 is fixed to a fitting member 9 and supports the whole bar-shaped vibration element. In the present embodiment, the vibration element is formed so that all its members except the flange-shaped elastic member 5 have the same outer diameter.

When a driving signal is applied to the piezoelectric element 3 from an unshown driving circuit, a primary bending vibration is excited in the bar-shaped vibration element thus formed and further a primary circumferential out-of-plane bending vibration including no circle to be a node of the vibration is excited in the flange-shaped elastic member 5.

At that time, the position of the anti-node of the primary bending vibration which is displaced in a radial direction and is excited the above-mentioned bar-shaped vibration element is arranged in a position off the center surface of the flange-shaped elastic member 5. The "radial direction" used herein denotes a direction included in a plane orthogonal to a straight line passing through the respective centers of the first elastic member 1, the flange-shaped elastic member 5, the piezoelectric element 3, and the second

elastic member 2.

As the bending vibration generated in the bar, a higher-order vibration such as a second-or third-order vibration also may be used without causing any problem. In such a case, however, it is necessary to dispose the flange-shaped elastic member 5 in a position off the position of the anti-node of such a vibration.

Next, the following description is directed to the driving principle of the present invention.

It has been known that when an out-of-plane bending vibration is excited in a disc and is allowed to travel, a circular or elliptical motion is produced at the surface of the disc.

In this connection, a device having a vibration mode as shown in FIG. 2A is disclosed in Japanese Patent Application Laid-Open No. 4-91668 as one with a similar shape to that of the bar-shaped vibration element of the present embodiment. However, in the case of the configuration in which the center surface 8 of the flange-shaped elastic member coincides with the substantially center position A of the anti-node of a bending vibration of a bar as in the case of the mode shown in FIG. 2A, the flange-shaped elastic member makes only a translation motion in the radial direction by a primary bending vibration.

On the contrary, when the center surface 8 of the flange-shaped elastic member is in a position off the

center position A of the anti-node of the bending vibration of the bar-shaped vibration element whose mode is shown in FIG. 2B showing the present embodiment, besides the translation motion in the radial direction, the flange-shaped elastic member can excite a rotational motion about an axis perpendicular to the axis of the bar-shaped vibration element (the axis orthogonal to the x-axis and z-axis in FIG. 2B). Hence, since the displacement including a thrust direction component and inertial force accompanying the displacement act on the vicinity of the outer periphery of the flange-shaped elastic member, the flange-shaped elastic member also can produce a vibration including the displacement component in the thrust direction, i.e. out-of-plane bending deformation. In addition, since the bending vibration excited in the bar-shaped vibration element rotates about the axis, the inertial force as a force for exciting the bending vibration acting on the flange-shaped elastic member travels on the periphery of the flange-shaped elastic member and the out-of-plane bending vibration of the flange-shaped elastic member also travels accordingly.

It is a well-known phenomenon that the elliptical motion is produced at the flange-shaped elastic member surface when a travelling out-of-plane bending vibration is generated in a flange-shaped object. Hence, when the rotation direction of this elliptical

motion is allowed to coincide with the rotation direction of a circular or elliptical motion produced in the flange-shaped elastic member by the rotation of the bending vibration of the bar-shaped vibration element, the rotational speed of a rotor pressed by the flange-shaped elastic member is increased and thereby the motor performance is improved.

When the flange-shaped elastic member is provided below the center position of the anti-node of a bending vibration acting on the flange-shaped elastic member, the location where the rotor and the vibration element is in contact with each other can be lowered and thereby the size of the whole vibration wave driving apparatus can be reduced.

FIGS. 3A and 3B each show a vibration mode in which a bending vibration of the bar and a bending vibration of the flange-shaped elastic member including no circle to be a node of the vibration are coupled with each other. FIGS. 4A and 4B each show a vibration mode in which a bending vibration of the bar and a bending vibration of the flange-shaped elastic member including one circle to be a node are coupled with each other.

All the orders in the circumferential direction are 1 (1 wave).

With respect to the direction of the circular or elliptical motion produced by the bending travelling

wave of the flange-shaped elastic member, the directions at points B1 and B2 are opposite to each other in FIGS. 3A and 3B, the directions at points B3 and B4 are opposite to each other in FIGS. 4A and 4B, and furthermore the directions at points B3 and B3' and the directions at points B4 and B4' each also are opposite to each other. The relationship between the points B3 and B3' and that between the points B4 and B4' each correspond to the relationship between the inside and outside of a node circle.

When driving the bar-shaped vibration element, the posture of vibrations largely depends on the relationship between the out-of-plane bending natural vibration frequency of the flange-shaped elastic member and the bending vibration frequency of the bar-shaped vibration element. Hence, the shape of the flange-shaped elastic member is determined so as to allow the generation of an out-of-plane bending vibration whose direction coincides with the rotation direction of the elliptical motion at the contact portion coming into contact with the rotor that is produced by the rotation of a bending vibration of the bar-shaped vibration element.

Second Embodiment

FIG. 5 shows a second embodiment of the present invention.

In a vibration element of a vibration wave driving

apparatus of the present invention, a flange-shaped elastic member 15 is formed integrally with a first elastic member 11, a piezoelectric element 13 is disposed between the flange-shaped elastic member 15 and a second elastic member 12, and the piezoelectric element 13 is sandwiched and fixed between the first elastic member 11 and the second elastic member 12 with an unshown fastening means. As the fastening means, for example, a screw member or the like may be used that is disposed inside the first and second elastic members 11 and 12 and passes through the piezoelectric element 13.

In the present embodiment, the vibration element is configured so that its upper and lower ends have increased outer diameters by means of a portion 11a provided for the first elastic member 11 and the second elastic member 12. This allows the natural vibration frequency of the vibration element as a whole to be reduced and thereby allows the vibration element to have a shortened axial length as compared to those whose natural vibration frequency is equal to that of this vibration element.

Furthermore, in the present embodiment, a member 17 having abrasion resistance is attached to a frictional portion subjected to friction with an unshown rotor on one surface of the outer peripheral portion of the flange-shaped elastic member 15 as a

flange-shaped protruding portion. Since the frictional member 17 is disposed, it is no longer necessary to carry out lapping process with respect to the flange-shaped elastic member.

Third Embodiment

FIG. 6 shows a third embodiment of the present invention.

A vibration element of the present embodiment includes a first elastic member 21, a second elastic member 22, a piezoelectric element 23, and a flange-shaped elastic member 25 as well as an unshown fastening means as in the first embodiment. The present embodiment is different from the first embodiment in that a protrusion 25a is formed in the outer peripheral portion of the flange-shaped elastic member 25 and a circular groove 25b is provided on the inner peripheral side with respect to the protrusion 25a.

As a result, the flange-shaped elastic member 25 is configured to have an increased weight at its outer peripheral end portion and lower stiffness on its inner peripheral side. Thus, an out-of-plane displacement is augmented in the outer peripheral portion of the flange that comes into contact with a rotor and thereby the rotational speed of the rotor further increases.

Fourth Embodiment

FIGS. 7A and 7B show a fourth embodiment of the present

invention; FIG. 7A is a perspective view of a vibration element and FIG. 7B is a cross-sectional view thereof.

Similarly in the present embodiment, a flange-shaped elastic member 35 and a piezoelectric element 33 are sandwiched and fixed between a first elastic member 31 and a second elastic member 32. The present embodiment is different from those described above in that circumferential protrusions 35a are provided in the outer peripheral portion of the flange-shaped elastic member 35 and the protrusions 35a are separated from one another in the circumferential direction.

Consequently, the stiffness is not increased when the flange-shaped elastic member 35 is subjected to out-of-plane bending deformation. Hence, a considerable out-of-plane bending displacement is obtained.

In addition, since the circumferential displacement component of an elliptical motion produced by travel of the out-of-plane bending deformation of the flange-shaped elastic member 35 is increased, it is possible to increase the rotational speed of a rotor, i.e. motor output.

Fifth Embodiment

FIG. 8 shows a vibration element according to a fifth embodiment of the present invention. This vibration element is obtained through further improvements made in the vibration element of the third

embodiment.

A piezoelectric element 43 for exciting an out-of-plane bending vibration is attached to the bottom face of a flange-shaped elastic member 25.

When the inertial force alone is not sufficient to be used as the out-of-plane bending vibration exciting force, a displacement is augmented using stretching force in the circumferential direction of the piezoelectric element. As an alternating signal, one used for driving the bar-shaped vibration element may be shared or another one may be provided.

Sixth Embodiment

FIG. 9 is a structural view of a bar-shaped vibration wave driving apparatus with the vibration element of the second embodiment.

As shown in the figure, in the bar-shaped vibration element of the present embodiment, a first elastic member 51, a second elastic member 52, a piezoelectric element 53, and a flange-shaped elastic member 55 are fastened together with a vibration element holding volt/supporting pin 56 as a fastening member. In addition, a fitting flange 59 to be fitted into a product is screwed and joined with a portion of the pin 56 located on position opposite to the second elastic member 52. An output gear 64 is attached to the fitting flange 59 to be rotatable about the center of the axis of the vibration element. A rotor 60 is

disposed around the first elastic member 51. The rotor 60 is provided with a contact spring 61 formed by press-forming that is adhesively secured thereto on its outer peripheral side and a spring case 62 that is engaged and joined therewith on inner peripheral side of the rotor 60. The spring case 62 is regulated by and fixed to the output gear 64 by its upper end portion so as not to be displaced relative to the output gear 64 in the radial direction. A spring 63 for applying pressing force is disposed between the lower end of the spring case 62 and the output gear 64. By the spring force of this spring 63, the spring end of the contact spring 61 fixed to the outer peripheral portion of the rotor 60 is in pressure contact with the upper surface of the flange-shaped elastic member 55. The fitting flange 59 also has a function of additional mass for preventing vibrations from leaking to the outside from the vibration element holding volt/supporting pin 56.

In the present embodiment, the vibration element is fixed and the rotor as a contact member that is brought into pressure contact with the vibration element is provided movably. However, the present invention is not limited to this. The contact member may be fixed and the vibration element may be provided movably, and the vibration element and the contact member may be frictionally driven relative to each

other by the driving vibration generated in the flange-shaped elastic member protruding in a flange form of the vibration element.

Similarly in the second to sixth embodiments, it is to be understood that the center surface of the flange-shaped elastic member is arranged in a position that does not coincide with the position of the anti-node of a bending vibration of the bar-shaped vibration element although it is not shown in the figures.

As described above, the embodiment described above employs the configuration in which a flange-shaped elastic member with a frictional surface is provided for a bar-shaped vibration element and driving force is derived through the frictional surface as well as the configuration in which an elastic member protruding from the flange-shaped elastic member portion is provided and the resonance frequency is lowered with this spring-mass system. Hence, the spring can be made considerably soft so that the resonance frequency is decreased to a sufficiently low level, i.e. the resonance frequency can be decreased to a sufficiently low level even when the diameter of the elastic member is reduced considerably.

Furthermore, when the protruding elastic member portion is formed of metal, even in the case where distortion concentrates thereon, the increase in internal loss stays within a minimum range since

damping characteristic of the metallic material is better than that of the piezoelectric element and thus a short vibration element with high efficiency can be obtained.

In addition, to driving force generated by a first travelling wave produced around the axis of the bar-shaped vibration element can be added driving force generated by a second travelling wave excited in the flange-shaped elastic member. Hence, a sufficiently great driving force can be obtained through mere application of a smaller driving signal than conventional one to an electro-mechanical energy conversion element.

Moreover, since the rotor can be disposed around the protruding elastic member, the overall length as the motor also is reduced.

The invention may be embodied in other forms without departing from the spirit or essential characteristics thereof. The embodiments disclosed in this application are to be considered in all respects as illustrative and not limiting. The scope of the invention is indicated by the appended claims rather than by the foregoing description, and all changes which come within the meaning and range of equivalency of the claims are intended to be embraced therein.